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A Consideration of the Action of the Extrinsic and Intrinsic Muscles of the Foot from an Anatomical and Mechanical Standpoint

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A CONSIDERATION OF THE ACTION OF THE EXTRINSIC AND INTRINSIC MUS- CLES OF THE FOOT FROM AN ANA- TOMICAL AND MECHANICAL STAND- POINT.

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THE following paper has nothing new to offer in regard to the anatomy and the amount of motion in the various joints of the foot, but it does present a different point of view than is usual in regard to the mechanical action of the muscles of the leg and foot. This is based on the study of wet ligamentous and tendinous specimens; of articulated bones of the foot and of a large series of cases seen clinically.

It is necessary first to review the literature of the anatomy in order to see just at what particular joints most of the motion from supination to pronation occurs.

It has been shown that there is no lateral mobility of the astragalus between the internal and external malleoli; that this is a tightly mortised joint at any angle of flexion or extension, owing to the shape of the malleoli and of the body of the astragalus and the angle at which these are

articulated. Therefore, motion of the internal malleolus is not possible without similar motion of the body of the astragalus. The importance of this will be brought out later.

The greatest amount of motion from supination to pronation that occurs at any joint takes place between the astragalus and the calcaneus. The angle of this joint line, owing to the articular facets, is such that the calcaneus, if the astragalus is held firmly without any rotation, rotates not directly from side to side but slightly in an oblique direction, so that in pronation the tuberosity or posterior end of the calcaneus has moved outward and rotated so that the internal tubercle is brought into more intimate contact with the ground. This is true without weight bearing. With weight bearing the converse happens. The calcaneus being on the ground cannot shift its position except by rotation on the tuberosity so the astragalus and the tibia must move unless held in place by muscles and ligaments. The motion of these latter bones is inward, downward and backward, which means that the body of the calcaneus must also move downward and inward, rotating on the posterior part or the weight-bearing surface of the tuberosity as an axis.

The astragalo-scaphoid joint has the next largest amount of motion from supination to pronation. The strong ligament which runs from the sustentaculum tali of the calcaneus to

the scaphoid forms nearly one-half of the articular surface of the astragalo-scaphoid joint. When the foot is pronated this is necessarily one of the first ligaments to be strained, because the head of the astragalus, following the motion of its body, as shown by the internal malleolus, moves downward, inward and slightly backward, thereby pushing more on the ligamentous and less on the bony part of this articulation.

Without weight bearing, if the astragalus is held in a fixed position the foot may be markedly pronated by outward rotation of the calcaneus without any motion of the astragalo-scaphoid joint. This pronation may now be increased by grasping the forefoot and forcing it outward. This increased motion takes place in several places; mostly in the astragalo-scaphoid joint and to a much less degree in the scaphoid, cuneiform and cuneiform metatarsal joints. There is also some motion but a practically negligible amount in the calcaneo-cuboid and cuboid-cuneiform and cuneiform-metatarsal region.

With weight bearing, since the heel and the head of the metatarsals are fixed on the ground, the motion of pronation must take place in the tarsal joints between the calcaneus and metatarsals and this is shown by the change of position of the internal malleolus.

Concerning the ligaments and muscles of the foot a vast quantity of literature has been written and many different opinions have been ex-

pressed. Certain German articles lately have been emphasizing the importance of the flexor longus hallucis, practically saying that weakness or atrophy of this is the cause of flat and pronated feet. Others hold that the intrinsic muscles of the feet are more important.

Another article which has appeared recently brings out the importance of the external rotators of the thigh in the correction of pronated feet. When the pronated position is long continued in certain types of feet the strain and consequent weakness which comes to the external rotators may be an important factor not only as to the back pain which may come from this trouble, but also is a point not to be overlooked in the proper treatment of foot strain.

The studies for this paper have led to the belief that neither weakness nor atrophy of any one muscle, nor bad shoes and stockings are a sufficient explanation of pronated or flat feet. They are undoubtedly very important factors and may be expected sooner or later to cause symptoms if they are combined with or are continued long enough to cause a faulty muscular balance. The importance of the correct muscle balance will be explained later on.

The muscles of the foot, for convenience, may be divided into two groups. One, the extrinsic muscles, which have their origin in the leg and their insertion into the bones of the foot; the other, the intrinsic muscles which have their ori-

gin and insertion in the foot alone. In a foot working under the best mechanical conditions either one of these two groups is necessary to the other. The intrinsic muscles hold the bones so that the extrinsic ones can apply their power to the best advantage and *vice versa*, but this will be explained more fully later.

The extrinsic muscles may be divided into three groups: (1) those which pass below and around the internal malleolus, (2) those below and around the external malleolus, and (3) those on the dorsum of the foot. The Achilles tendon is not considered because its action, although it tends to correct rotation of the os calcis to a very slight extent, is as a whole secondary, in this correction, to the action of the other foot muscles.

The muscles which pass below and around the internal malleolus are three (see Fig. 1)—the tibialis posticus, which arises from the posterior surfaces of the tibia and fibula and forms a tendon which passes below and around the internal malleolus to its insertion on the lower surface or tuberosity of the scaphoid and then spreads out to the sole of the foot; the flexor longus digitorum, which arises from the back of the tibia, close to the posticus and forms a tendon which passes around the internal malleolus, just below the posticus tendon in a groove at or near the tip of the sustentaculum tali and then runs forward to be inserted in the terminal phalanges

of the four outer toes; the flexor longus hallucis arises from the posterior surface of the fibula; its tendon passes downward through a groove on the posterior and inner side of the astragalus and thence forward under the sustentaculum tali to be inserted into the terminal phalanx of the great toe, with an insertion also in the long tendon of the second toe.

Consider now the action of these muscles on the bones of the foot without weight bearing and then with weight bearing.

First, with the malleoli fixed or without weight bearing. The tibialis posticus as it is inserted into the lower surfaces of the scaphoid and the other tarsal bones when contracted will tend not only to supinate the foot with slight plantar flexion but also to adduct the foot, thereby assisting the action of the tibialis anticus.

The long flexors of the toes and of the great toe, when contracted, first flex the distal phalanges of the toes and then, by their leverage on the sustentaculum tali, which is placed just a little in front and to the inner side of the line of the astragalo-calcaneal joint, rotate the rear end or tuberosity of the calcaneus slightly inward and upward.

With weight bearing the heel and toes being on the ground cannot move if these muscles are contracted. Therefore, since these muscles are not strong enough to lift the whole body weight

and since the force of their contraction is applied, like a bowstring, to the internal malleolus and to the sustentaculum tali and astragalus and since these latter bones are not fixed, by reason of the possible rotation of the leg and thigh above them, whatever motion occurs as a result of the contraction of these muscles must be in the direction in which their force is applied on the movable bones. The direction of this force on the internal malleolus is forward, upward and outward or just the reverse of that which takes place at the malleolus when the foot is pronated. The result of this force on the sustentaculum tali must be to rotate the calcaneus upward and outward or if the foot is in a valgus position, to correct the valgus of the calcaneus. This latter point is very important in regard to treatment.

The extrinsic muscles below and around the external malleolus are only two. The peroneus longus arises from the head and anterior surface of the fibula and the intermuscular septum, passes as a tendon downward in a curve behind and below the external malleolus along a groove on the outer side of the calcaneus to another on the lower surface of the cuboid where it is inserted on the under and outer surfaces of the first cuneiform and the first metatarsal.

The peroneus brevis arises from the anterior surface of the fibula, below the longus, its tendon passing downward in a curve below and around

the external malleolus to the tuberosity of the fifth metatarsal.

Without weight bearing the action of these two muscles is to flex the foot plantarward and to pronate it. With weight bearing, since the foot can neither move plantarward nor pronate, the force of the contraction must be on the external malleolus. The direction of this force is forward and slightly upward, which is just the opposite of what occurs at the internal malleolus when the muscles there contract. In other words, it forces the foot into a more or less pronated position.

The extrinsic muscles on the dorsum of the foot are four in number. The *tibialis anticus* arises from the upper and outer side of the tibia and the interosseous membrane and passes as a flat tendon downward beneath the strong anterior annular ligament of the ankle to be inserted into the plantar surface of the internal cuneiform and the first metatarsal. The *extensor longus digitorum* arises from the head of the fibula, tibia and intermuscular septum and passes as a tendon below the anterior annular ligament to be inserted into the four outer toes. The tendon going to the fifth toe is usually associated with a small muscle called the *peroneus tertius*.

The *extensor longus hallucis* arises from the interosseous membrane and the fibula and passes as a tendon below the anterior annular ligament

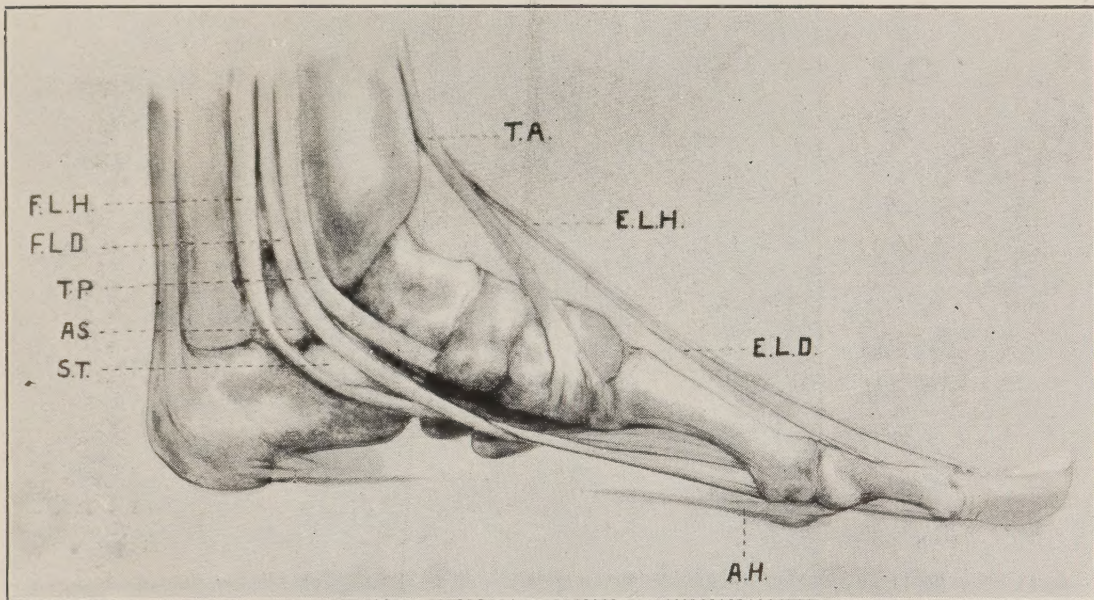


FIG. 1.—Drawing of ligamentous and tendinous specimen of foot (somewhat diagrammatic). *F. L. H.*, flexor longus hallucis; *F. L. D.*, flexor longus digitorum; *T. P.*, tibialis posticus passing behind internal malleolus; *A. S.*, astragalus showing groove for flexor longus hallucis; *S. T.*, sustentaculum tali showing how flexor longus hallucis passes below it like a bow-string; *A. H.*, adductor hallucis; *T. A.*, tibialis anticus; *E. L. H.*, extensor longus hallucis; *E. L. D.*, extensor longus digitorum.

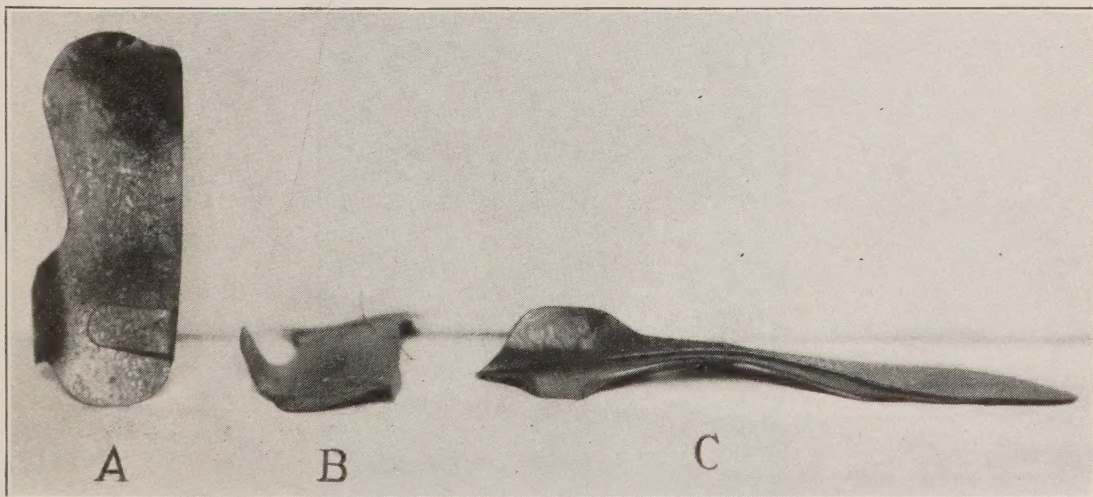


FIG. 2.—*A*, method of making flange to tilt heel; *B*, the average height of flange; *C*, the finished plate.

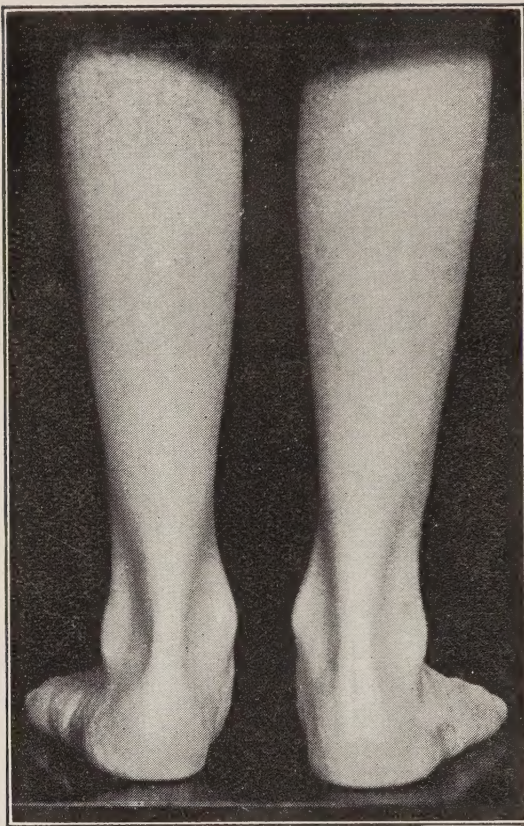


FIG. 3.—Showing marked pronated and abducted feet; note rotation of the os calcis.

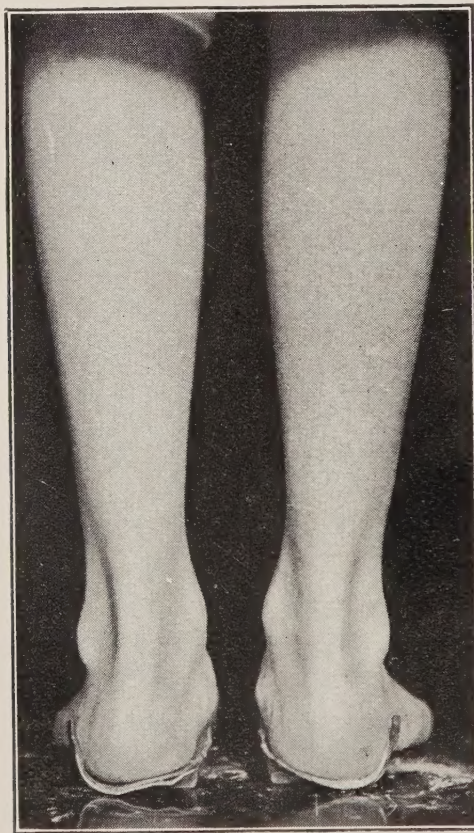


FIG. 4.—Showing the way the tilted heel plate tends to correct the abduction and the rotation of the os calcis, thereby making possible the more perfect action of the muscles around and below the internal malleolus.

to be inserted into the base of the terminal phalanx of the great toe. The action of these muscles alone, without the external or internal muscles, is to dorsally flex the foot and toes and to lift the outer and the inner edge of the foot. The action of the tibialis anticus with weight bearing is dependent to a large extent on the position of the foot. If the internal group of muscles is the stronger, as is normal, it tends to increase the varus position. If the external muscles are the stronger, it then tends to increase the valgus position. The action of these muscles, therefore, is to a large extent dependent on the normal actions of the two other groups of muscles.

The intrinsic muscles of the foot play a very important part in the condition of the foot in that it is due to the proper working of them that the extrinsic muscles can apply their force to the greatest advantage. There is no necessity to take each muscle up in turn. It is sufficient to take one muscle as an example.

The adductor hallucis arises from the inner tubercle of the os calcis and the plantar fascia and some of the ligamentous structures near by. Its tendon is inserted along with the flexor brevis hallucis into the inner side of the base of the first phalanx of the great toe. This action in connection with the flexor longus hallucis is very important. The adductor and short flexor, with weight bearing, tend to hold the base of the first

phalanx and, therefore, the head of the first metatarsal down on the ground and so shorten the length of pull of the long flexor and give this tendon more purchase on the internal malleolus. The adductor hallucis also tends to keep the os calcis from getting into a valgus position because of its action on the tuberosity of the os calcis, which is posterior to the astragalo-calcaneal joint.

With an anatomical knowledge of what occurs in the foot when the position of pronation is assumed, it is easy to understand how unequal a strain comes upon the muscles of the foot. This strain is mostly on those extrinsic muscles which are below the internal malleolus and also on their helpers, the intrinsic muscles. Owing to the position taken by the bones in pronation these muscles are not only stretched, but also, and this is of more importance, are put into a position in which mechanically they are less well able to apply the force of their contraction to the full extent. These two factors when present must necessarily tend to weaken those muscles under tension and so to cause a greater or lesser change in the normal muscular balance of the foot. These latter facts are of great interest from the point of view of treatment, preventive as well as curative.

In the line of preventative treatment anything which will tend to keep the muscular and ligamentous balance of the foot in its normal relation

is of the greatest importance and, therefore, anything which will give an idea as to whether the muscles of a foot are in normal balance or not will be of great assistance. The method and apparatus devised by Osgood for testing the comparative strength of the abductors and adductors, readily gives one an idea as to the best plan of treatment to be followed. The normal relation of adductors slightly stronger than abductors, has been well shown by Osgood in a series of examinations of some 200 nurses' feet at the beginning of their training and then subsequently through their course. By this determination of the muscle balance and by advice based upon it, not one nurse was laid off duty for foot trouble during the past year.

As for curative treatment, every orthopedic man has his own method which has given him the best results. Some use exercises only; some use plates only; some use both, with and without Thomas heels, proper shoes, etc. All of these methods are undoubtedly of value when they are properly carried out by the patient but they are often difficult. One of the difficulties of the exercise treatment for a certain relaxed type of feet is that only while the exercises are being done are the muscles being properly used, all the rest of the time, which is by far the longest, these muscles are not only being constantly stretched as is shown in this picture (Fig. 3), but also are being used in a position that mechanically

and anatomically is most difficult for their proper action. Thomas heels in these marked cases are not enough to hold the feet in a position to relieve this strain. On the other hand, the use of the ordinary plate has its distinct disadvantages. The average plate is planned to hold up the arch of the foot by pressure from beneath and so force the bones into as near a normal position as possible. There are plates which apply this pressure at almost any part of the sole but they usually apply it in the region of the scaphoid. The result of this is that the patient very soon begins to depend entirely on the plate to hold up his arch, as is shown by the way some plates are constantly broken and by the atrophy of the foot muscles after wearing such a plate.

A plate of this kind seems to me to be wrong mechanically and anatomically because it applies its force in the wrong place. As has been shown above, the greatest amount of pronation takes place first in the calcaneo-astragaloid joint and then in that between the astragalus and the scaphoid. Now if a plate is made so that it prevents pronation or valgus of the calcaneus, when the foot is first put to the ground, the muscles of the foot are placed at the beginning of their action so that they can mechanically apply their force to the greatest advantage. The place where this muscular force is applied is, as has been shown above, not at the attachments

of the muscles but at the internal malleolus and the sustentaculum tali; the direction of this force causes the forward and upward rotation of these ankle bones and so raises the scaphoid and the arch of the foot.

A plate which accomplishes this, as it allows the muscles to work with the least possible strain will not tend to atrophy the muscles but to rest and thereby strengthen them. Combine such a plate with exercises and it is reasonable to expect the best and quickest results.

A plate has been devised to do this. It is very simply made. It combines the idea of a Thomas heel and the ordinary plate. The tilting of the heel of the plate is done by making an inside flange at the back of the heel which, in finishing, is turned underneath to extend half way across the heel. By only going half way across, the outside of the plate is kept low, while the inside can be made of any height desired. The outside heel flange keeps the foot from sliding off the plate (see Fig. 2). The rest of the plate is made to give as little or as much support as is desired. This plate can be made of a lighter gauge of steel than the ordinary plate because less direct weight comes on its weakest part.

Conclusions.—1. When a foot strikes the ground the first motion in pronation begins at the calcaneo-astragaloid joint and then is con-

tinued by the astragalo-scaphoid and the other small joints in this region.

2. When the weight of the body is on the foot the application of the force of the contraction of the foot and leg muscles is not the same as when there is no weight on the foot.

3 Without weight bearing the force of contraction is applied mostly at the insertion of the muscles and the foot is consequently moved.

4. With weight bearing the foot cannot move and so the force is applied not at the insertion of the muscles but by their tendons at those points where motion is most easily possible.

5. With weight bearing it is possible to rotate outward or inward the tibia and fibula and, therefore, the astragalus and so to correct or increase pronation.

6. The adductor muscles of the foot are normally stronger than the abductor.

7. With weight bearing the force of the adductor muscles is applied not at their insertion but by their tendons at the internal malleolus and the sustentaculum tali, thereby tending to push these forward, upward and slightly outward and so correct pronation.

8. In weak and relaxed feet pronation may be most easily and beneficially corrected by preventing its occurrence at the calcaneo-astragaloid joint and the beginning of weight bearing.

9. A simple way to accomplish this is by the use of a plate with a tilted heel, as described above.

10. The advantage of such a plate is that it puts the foot into the position best adapted for the proper use and exercise of the muscles.

11. Anything which will hasten the return of a normal muscle balance to the foot, be it plates, exercises or other methods, should be used and this paper is written in the hope that by giving a clearer idea of the true action of the foot muscles treatment of any kind may be regulated to bring about the desired result of a normal muscle balance and the use of no apparatus.

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